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An experimental investigation of sharp force skeletal trauma with replica Bronze Age weapons

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Abstract

Skeletal sharp force trauma provides direct evidence for the use of bladed weapons against humans. As such, it is an important source of evidence for examining the prevalence of violence and weapon use in the past. The primary aims of this study are to provide experimental evidence for the efficacy of Bronze Age weapons against skeletal tissue and to test the applicability of existing criteria for sharp force trauma analysis to Bronze Age skeletal material. To that end, three Bronze Age weapons - a dirk, flanged axe and Wilburton sword - were used to strike four Synbone spheres ('crania') and two cylinders ('long bones'). Subsequent damage to the weapons and Synbone was analyzed using macroscopic and microscopic methods including digital photography, three-dimensional digital modelling, and metric analysis. The results of the study suggest the Wilburton sword and flanged axe could be effective weapons in combat and existing methods for cutmark analysis are generally applicable to injuries created with Bronze Age weapons when taking into account the size of the weapons. Sword (slashing) and axe (chopping) trauma can be distinguished on the artificial bone material based on the degree of wastage and fracturing. Further research is needed to develop criteria for distinguishing sword and dirk trauma as sword trauma was not distinguishable from knife weapon classes. Additionally, Synbone may not be an ideal skeletal tissue analogue in sharp force trauma research as it does not record the microscopic striations created by a blade passing through bone.

1. Introduction

The European Bronze Age (BA), c.2300–c.700 BCE (Coles and Harding, 1979; Kristiansen and Larsson, 2005), is an important period in the 'history of violence' as it marks the first time when weapons can be understood as being designed specifically to kill humans (Molloy, 2010). Despite this, or perhaps because of it, the prevalence of violence and warfare during the Bronze Age period has been a topic of considerable debate during the last several decades (Mödlinger et al., 2011). Notwithstanding the numerous weapon finds and the centrality of metalworking typologies in the assignment of chronology in the period, the Bronze Age was for many years understood to be a relatively peaceful period in human history in which weapon finds have been interpreted to be ceremonial rather than functional objects (Fyllingen, 2003; Mödlinger, 2011; Thrane, 2006). In recent years, some scholars have challenged this interpretation of the period and argued instead that BA weapons could have been functional and efficient (e.g. Anderson, 2011; Dolfini and Crellin, 2016; Horn, 2013; Kristiansen, 2002; Molloy, 2007).

Skeletal trauma provides a relatively unique source of evidence to clarify our understanding of violence and weapon use in the BA, as it is our most direct source of evidence for violence in the past (Larsen, 1997). Despite this, skeletal trauma has been under-utilized as a source of evidence in discussions on the prevalence of violence in the BA and the functionality of BA weaponry (e.g. Harding, 2000; Ucklemaun and Mödlinger, 2011). The primary aims of this provisional study are to: a) test the applicability of current methods for studying skeletal sharp force trauma (SFT) to trauma inflicted with BA weapons, b) provide experimental evidence for the use and effectiveness of BA weapons against skeletal tissues, and c) test the use of Synbone (synthetic human tissue) as a human hard tissue analogue in SFT research.

Previous research on weapons-trauma in BA skeletal collections has been fairly limited, particularly in the field of sharp force trauma research. Studies into the skeletal evidence for

interpersonal violence tend to focus on blunt force trauma (BFT), projectile injuries, and ante-mortem (AM) injury (e.g. Aranda-Jimenez et al., 2009; Gasperetti and Sheridan, 2013; Jantzen et al., 2011). Studies that do mention SFT in the BA generally do not diagnose injuries to a specific weapon class (e.g. Erdal, 2012; Fyllingen, 2003; Louwe-Koojimans, 1993; Smith, 2009).

Much of the skeletal evidence of SFT and projectile injuries from the period comes from small numbers of individuals displaying weapon wounds. For evidence of projectile injuries see Osgood et al. (2000) and Osgood (2005) and Smith (2009); for blade injuries identified as sword cuts (mainly to the skull) see Mödler (2011) and Thorpe (2006). Individuals with SFT from other implements possibly daggers or knives and axes are quite rare but have also been noted at several locations (e.g. Jimenez-Brobeil et al., 2014; Smith, 2009; Waddell, 1984). While Skeletal evidence of violence on a larger scale has been fairly limited, several sites have also been suggested as possible indicators of BA battles/massacres based on the prevalence of skeletal trauma (e.g. Erdal, 2012; Fyllingen, 2003; Harde, 2005; Harding, 2007; Jantzen et al., 2011; Louwe-Koojimans, 1993).

Previous research in both skeletal sharp force trauma analysis and experimental combat provides a methodological framework for the recording and interpretation of cutmarks made by different classes of weapons (e.g. Capuani et al., 2014; Humphrey and Hutchinson, 2001; Lewis, 2008; O'Flaherty, 2007, Reichs 1998). Unfortunately, very little work in the field of cutmark analysis focuses on SFT from a combat perspective. Both archaeological and forensic cutmark analysis has focused primarily on stabbing and cutting with small weapons like knives in the context of homicides (e.g. Crowder et al., 2013; Shaw et al., 2011; Thompson and Inglis, 2009) and butchery or ritual activity (e.g. Scalping) (e.g. Bonney, 2014; Boschini and Crezzini, 2012; Bromage and Boyde, 1984). Studies that involve chopping weapons, such as axes, have been limited and generally do so in the context of butchery and dismemberment rather than combat (e.g. Alunni-Perret et al., 2005; Reichs, 1998; Shipman, 1981).

Experimental weapons testing is an area of research which has proven useful not only in testing the combat capabilities of weapons (e.g. Anderson, 2011; Molloy, 2004), but also in determining skeletal weapons-trauma patterns (e.g. Lewis, 2008; Novak, 2000; Wenham, 1989). Unfortunately, studies that have examined SFT from a combat perspective generally examine weapon injuries from modern or medieval weapons (e.g. Inglemark, 1939; Lewis, 2008; Novak, 2000). Furthermore, research conducted on the combat capabilities of BA weapons has focused almost exclusively on the damage to the weapon blades with only cursory, if any, assessment of osteological evidence (e.g. Anderson, 2011; Dolfini, 2011; Horn, 2013; Molloy, 2007; O'Flaherty, 2007). BA weapons are mechanically, and therefore functionally, different from later blades and as such, I would argue that the applicability of methods for the study of skeletal SFT to BA skeletal material has not yet been demonstrated.

Experimental studies have also predominantly relied on the use of animal analogies for human tissue (e.g. Cerutti et al., 2014; Donnellan, 2010; Lewis, 2008; Thompson and Inglis, 2009) despite several important limitations such as differing size, shape and thickness of bone and overlying soft tissue structures (Pounder et al., 2011; Smith et al., 2015). Due to the ethical implications of using human tissues for experimentation (e.g. Human Tissues Act, 2004¹), non-human tissues are often the most feasible options for experimentation despite these limitations. This study tested the use of Synbone (synthetic bone tissue) in SFT research. Synbone avoids many of the limitations associated with using animal tissues for experimentation as it is designed to replicate the structure and thickness of human bone (Gläser et al., 2011; Smith et al., 2015). Synbone has been demonstrated to be an adequate human tissue analogue in several BFT and ballistics studies (e.g. Gläser et al., 2011; Thali et al., 2002), however, it has not, to my knowledge, been previously tested in BA SFT research.

2. Materials and methods

Four Synbone² spheres were employed as analogues for the human cranium and two cylinders as analogues for human long bones, specifically the tibiae. Synbone is modified bone-like polyurethane designed to mimic the structure and thickness of human bone (Gläser et al., 2011;

Smith et al., 2015). The Synbone is coated in a rubber skin and was filled with a 10% gelatin solution (type 3 porcine ballistics gelatin) to simulate associated brain and internal soft tissue structures (as seen in Jussila, 2004). All metrics were recorded in millimeters using digital sliding calipers, a plastic tape measure, and a plastic ruler.

The Synbone spheres were placed on a cork ring on an impact force measurement system, set on a raised platform (total height 146 cm) in order to approximate the angle of attack between two opponents of similar height (Fig. 1). The cork ring was necessary to stabilize the spheres as well as absorbing some of the force of the impacts to simulate the elasticity of the spinal column (Thali et al., 2002). The spheres were further secured with a cardboard ring around their circumference to limit side to side movement from the impacts. The force of each strike to the spheres was recorded using the impact force measurement system³ (IMF-RAP3-750M) and LoadVUE (LV-1000HS-1K) software.

The Cylinders were held upright at the approximate height of tibiae by securing them against table legs with duct tape (52–53.5 cm height at the top of the cylinder). Furthermore, the table legs were covered with towels to provide a small amount of cushioning to simulate a small soft tissue component in the absorption of force (Thali et al., 2002).

Three replica BA weapons: a Middle Bronze Age dirk and flanged axe c.1800 BCE and an early phase Late Bronze Age sword (Wilburton Type) c.1100 BCE (Fig. 2) were employed to strike the Synbone. The replica weapons were made by Bronze Age craftsman Neil Burridge.⁴

Weapon measurements and micrographs of the blade edges were taken prior to use. Blade measurements followed the recommendations outlined in Lewis (2008). All metrics were recorded using digital sliding calipers, a plastic tape measure, and a plastic ruler. Weapon specifications can be found in Table 1; all linear measurements are in millimeters, weight is in grams.

The weapon strikes were designed to simulate a face-to-face combat situation between right-handed opponents as studies of archaeological skeletal populations with cranial trauma have demonstrated this pattern with a high frequency of wounds to the front and the left side of the cranium (e.g. Erdal, 2012; Fibiger et al., 2013; Fyllingen, 2003; Inglemark, 1939; Wakely, 1997; Walker, 1989). The strikes were executed by two different attackers and were delivered at one of two angles: perpendicular (approx. 90 degrees) or oblique (approx. 45 degrees) delivered from the right (Fig. 3) based on previous research that has noted the variability of wound morphology based on these differences (e.g. Humphrey and Hutchinson, 2001; Wenham, 1989). Attacker one was a right-handed, young, adult male martial arts expert (height 1.67 m, weight 78 kg) well acquainted with handling weapons. Attacker two was a right-handed, young, adult female height (1.80 m, weight 66 kg) familiar with the mechanics use of BA weaponry in combat (e.g. Amberger, 1998; Denny, 2006; Molloy, 2004, 2007; Turner, 2002). Prior to delivery of the strikes the attackers spent some time getting acquainted with the weapons to find the correct balance, stance and motion of the strikes⁵ (Molloy, 2007, p.99–102).

Osteological analysis of weapon damage to Synbone was conducted by MD. Analytical procedures followed those outlined in Brickley and McKinley (2004), Houck (1998), Lewis (2008), and Lovell (1997) and included macroscopic and microscopic examination of wounds in addition to creating digital 3D models of the damage.

Macroscopic examination included: photographs, following Gilbert and Richards (2000) and Houck (1998); metric assessment based on Cerutti et al. (2014) and Lewis (2008); and detailed descriptions of wound morphology following procedures and terminology (Fig. 4) outlined in Boutros-Ghali (2008), Byers (2002), Humphrey and Hutchinson (2001), Lewis (2008), Lovell (1997), Reichs (1998), and Wenham (1989).

Initial macroscopic assessment was conducted with 'soft tissues' intact and then repeated after removal of skin and gelatin. Photographs were taken with a digital camera (Sony Cyber-Shot DSC-HX300) and measurements were recorded using digital sliding calipers. 3D digital models of the damage to the Synbone were reconstructed using a Panasonic PT-LB20NTEA surface scanner and AMIRA software (6.0) with the help of Helen Langstaff and Mara Karell, researchers proficient in the use of this software.

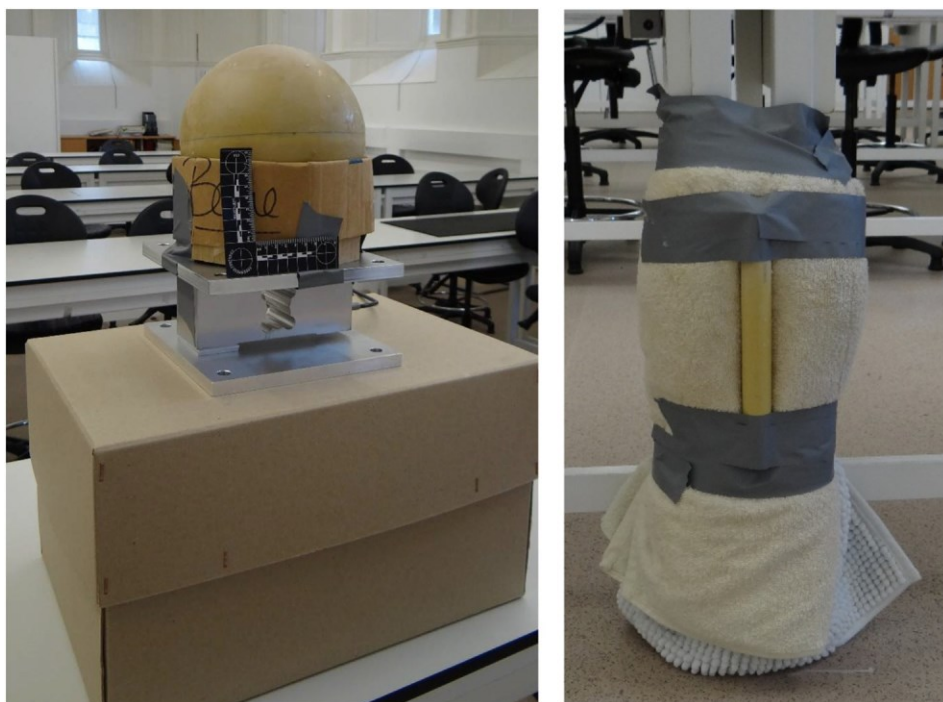


Fig. 1. Experimental set-up of Synbone.

Middle Bronze Age Dirk (c. 1800 BC)



Middle Bronze Age Axe (c. 1800 BC)



Late Bronze Age Sword (c. 1100 BC)



Fig. 2. Replica Bronze Age weapons.

In order to facilitate microscopic examination of wound patterns without cutting down the

Synbone specimens, negative casts of the wound impressions from the sword and dirk were created using Polycraft latex rubber. These models were then used to create positive casts of the weapon damage using casting resin (Crystics 9293 polyester casting resin).

Image capture and processing were performed with a Dino-Lite Pro (HR AD7013MZT) digital microscope with Dino-Capture 2.0 software and a traditional light microscope (Leica DM750P) with Leica application Suite (4.6).

Table 1. Metrical characteristics of replica BA weapons.

Weapon	Dirk	Sword	Axe
Total length	200	564	621
Blade length	191	446	51.1
Weight (inc. handle)	74.6	570	790
Handedness	1	1	2
Width of cutting edge	—	2.8	1.5
Thickness of cutting edge	~ 0.5	0.5	0.5
Max width (sup-inf.)	55	38.6	59.2
Max thickness (med-lat.)	4	6.9	8
Rivet caps (diameter)	~ 7	~ 2.7–3	N/A
Rivet holes	~ 6	~ 2.7–3	N/A
Blade composition	10% tin bronze	2% lead, 9% tin, 89% copper	12% tin bronze
Handle composition	Ash wood	Ash wood	Ash wood
Pommel (max diameter)	56.8		
Arm reach length			233

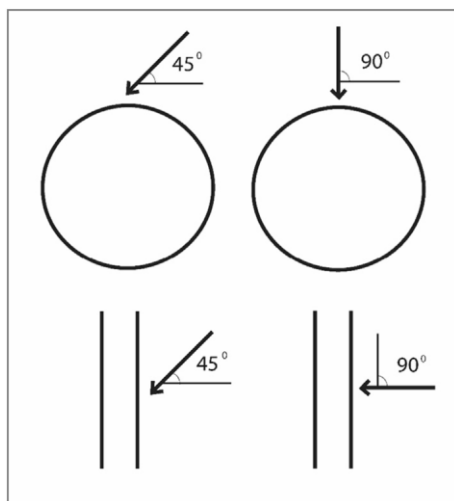


Fig. 3. Angle of strikes

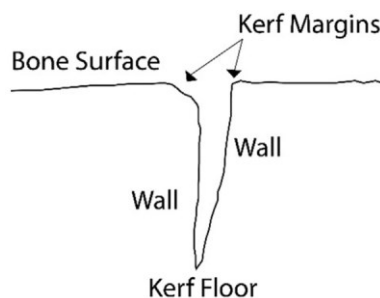


Fig. 4. Cutmark Terminology.

3. Results

SFT injuries are often divided into stab, cut/slash and chop wounds (Pollak and Saukko, 2009). Dirk strikes were stabs, defined as a pointed weapon penetrating the body/bone along its longitudinal axis (Pollak and Saukko, 2009). Sword strikes were delivered as cuts/slashes in which the edge of the blade is drawn across the target creating damage through laceration and incision (Molloy, 2007, p. 100). The axe strikes can be described as chops, which occur when an edged weapon creates damage through percussion, or ‘sharp-blunt trauma’ (Alunni-Perret et al., 2005, p.1). Details of the strikes employed in the study including the recorded peak force for each strike have been outlined in Table 2. Strike one missed the target and as such has not been included in further analysis.

Morphological features of the cutmarks have been outlined in Table 3. Strike 3 has not been included as it did not generate any hard tissue damage.

Table 2. List of strikes.

Weapon	Symbone			Strike ^a				Impact location	Peak force (N)
	Type	Number	Wall thickness (mm)	Shape	Number	Type	Attacker	Angle/Movement	
Dirk	A	7		Sphere	1	Stab	1	Downwards, over-arm, oblique	Missed
Dirk	A	7		Sphere	2	Stab	1	Downwards, over-arm, oblique	Left parietal
Dirk	A	7		Sphere	3	BFT with hilt	1	Downwards, over-arm, perpendicular	Right parietal
Axe	B	5		Sphere	7	Chop	2	Downwards, over-arm, perpendicular	Frontal
Axe	B	5		Sphere	8	Chop	2	Downwards, over-arm, perpendicular	Frontal
Sword	C	5		Sphere	9	Slash	2	Downwards, oblique, onside (aiming for left parietal)	Right parietal
Sword	C	5		Sphere	10	Slash	2	Downwards, oblique, onside, (angle was too steep & just nicked top). Direction: R to L	Top
Sword	D	5		Cylinde	5	Slash	2	Downwards, perpendicular, onside	Midway up shaft
Sword	D	5		Cylinde	6	Slash	2	Downwards, oblique, onside	Superior 2/3 of shaft
Axe	E	3		Cylinde	4	Chop	2	Downwards, perpendicular, side arm	Midway up shaft
Sword	G	5		Sphere	12	Slash	2	Downwards, perpendicular, onside	Left parietal
Sword	G	5		Sphere	11	Slash	2	Downwards, perpendicular, offside	Right parietal

a For Schematic of strike angle/movement see [Fig. 3](#).

4. Discussion

A key aim of this study was to determine the applicability of current methods for studying skeletal SFT to trauma inflicted with BA weapons. In order to test this, experimentally generated SFT with BA weapons has been compared to the criteria outlined in forensic and archaeological literature on cutmark analysis.

4.1. Axe trauma

The axe used in the current study can be classified as a chopping/ hacking weapon. Similar to later axes, the blade is wedge-shaped and as such, this weapon class creates damage through a combination of incision, with a sharp edge, and percussion, with the shape and weight of the blade (Alunni-Perret et al., 2005). The axe blade used in this study differs from later axe blades in size as it is comparatively smaller and less distinctly wedge-shaped. The axe used in this study was 0.5 mm thickness at the cutting edge and 7–8 mm thickness at the back of the blade in comparison to later axes, for example Humphrey and Hutchinson (2001), which were ~ 1.4 mm thickness at the cutting edge and ~ 30 mm at the back of the blade. Despite the small dimensions of the blade the injuries generated with the BA axe (n = 3) were generally consistent with previous research on SFT using chopping/hacking weapons such as axes, cleavers and machetes (e.g. Alunni-Perret et al., 2005; Humphrey and Hutchinson, 2001; Wenham, 1989).

Table 3. Morphological Features of Cutmarks.

Weapon Trait	Dirk Strike 2	Axe Strike 4	Sword Strike 5	Sword Strike 6	Axe Strike 7	Axe Strike 8	Sword Strike 9	Sword Strike 10	Sword Strike 11	Sword Strike 12
Cross-section	Irregular	V-shaped	V-shaped	V-shaped	N/A	N/A	V-shaped	N/A	V-shaped	V-shaped
Kerf	Narrow	Narrow-med	Narrow	Med-wide	Med-wide	Wide	Med-wide	N/A	Very narrow	Narrow
Size/Width										
Depth	Med	Shallow	Shallow	Shallow-med	Deep	Deep	Shallow-med	N/A	Shallow	Shallow
Length	Similar to width	Longer than width	Longer than width	Longer than width	Longer than width	Longer than width	Longer than width	N/A	Longer than width	Longer than width
Shape	Triangle	Line	Line	Ellipse	Narrow ellipse	Ellipse	Thin oval	Semi-circular	Line	Line
Feathering	No	No	No	No	Unilateral	No	Unilateral	No	No	Unilateral
Flaking	Unilateral	No	No	Unilateral	Unilateral	Bilateral	Unilateral	No	No	No
Fracture	No	Yes	No	Yes	Yes	Yes	No	Yes (hairline)	Yes	No
Breakage	No	Yes (complete)	No	No	No	No	No	No	No	No
Shards	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No
Striations	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Aspect	Oblique	Perpendicular	Perpendicular	Oblique	Perpendicular	Perpendicular	Oblique	Oblique	Perpendicular	Perpendicular
Total # of marks	1	1	2	1	1	1	1	1	1	1

Axe wounds were characterized by significant wastage, breakage and fracturing (Fig. 5). In the crania, fractures were primarily linear with one very fine concentric/depressed fracture on strike 7 (see Fig. 4). Cranial fractures were also mainly terminal, meaning they are situated in the same line as the injury itself and extend from roughly the ends of the kerf (Wenham, 1989). In the long bone, the fracture pattern is more irregular but it can be described as a spiral fracture (Waldron, 2009).

Interestingly, although the features of the axe trauma in the current study were generally consistent with criteria outlined in previous research, axe injuries in the current study did not create square-shaped or large notch/cleft-shaped defects sometimes seen in axe injuries (e.g. Boutros-Ghali, 2008). We would hypothesize this is perhaps due to the small dimensions of the BA axe blade compared with later axes particularly in terms of their wedge shape.

4.2. Sword trauma

The sword, as a weapon-type, is an extremely broad classification as sword morphologies can be highly variable. BA swords, including the sword used in the current study, are typically light and short, wielded with one hand and feature a double-edged blade (Harding, 1999; Kristiansen, 2002; Mödinger, 2011). Edged weapons can but used to cut flesh and/or bone by incision and percussion, incision and laceration or by percussion (Amberger, 1998, p.94). While there is some continued debate as to the mode of use of BA swords (i.e. slashing/stabbing) (Molloy, 2007), the sword in the current study was used in a slashing motion. Slashing involves incising and lacerating by drawing the blade across the target (Molloy, 2007, p.95). This type of attack generated defects consistent with the features of ‘incisions’ including v-shaped kerfs, narrow cross-sections and minimal wastage (Byers, 2002).

It has been demonstrated that the angle of a blow can have a significant impact on the morphology of the resultant wound (e.g. Maples, 1986; Wenham, 1989). The sword injuries have therefore been categorized based on the angle of the blow: roughly perpendicular to the bone surface or oblique at roughly 45°.

Perpendicular sword strikes ($n = 3$) present as characteristic SF incisions being longer than wide with shallow penetration; very narrow, v-shaped kerfs; straight, smooth walls and minimal fracturing and wastage (Fig. 6) as seen in Boutros-Ghali (2008) and Byers (2002). Oblique blows ($n = 3$) with the sword resulted in wounds that were more irregular in appearance nonetheless, two of the strikes (6 and 9), still maintained characteristic features of SF incisions including: shallow penetration, v-shaped kerf floors and fairly minimal wastage (Byers, 2002). Unlike the perpendicular sword strikes which created fairly narrow incisions at the wound margins with

vertical, roughly symmetrical walls, the oblique blows created much wider incisions at the bone surface with distinctly more angled/sloped walls. Although the cuts are wide at the surface of the bone, under microscopic examination, the kerf floors are still quite narrow (Fig. 7) as would be expected in SFT with a narrow blade.

4.3. Dirk trauma

Assessment of wound morphology generated with the BA dirk was limited in this study due to the failure of the blade during experimentation. When the dirk was used in a stabbing motion the tip of the blade bent on contact with the Synbone on the first strike, prohibiting further SFT blows using this weapon. The hilt of the weapon was therefore employed to examine the BFT capabilities of the weapon, however, this too damaged the weapon on the first strike prohibiting further testing. As the trauma analysis was based on only two strikes, one SF and one BF, and these strikes may have created atypical damage due to the breakage of the weapon, generalizations about wound morphologies created by BA dirks have not been attempted. It is interesting to note however, that the damage to the dirk in the current study replicated the damage seen in the original BA dirk that the experimental replica was modelled after. This raises questions about previous interpretations of the mechanisms of damage to BA weapons such as ‘ritual-killing’ of weapons (e.g. Barber, 2003; Osgood et al., 2000). Further discussion of this topic is beyond the scope of this study, however, research on this subject is being undertaken by Rachel Faulkner-Jones.

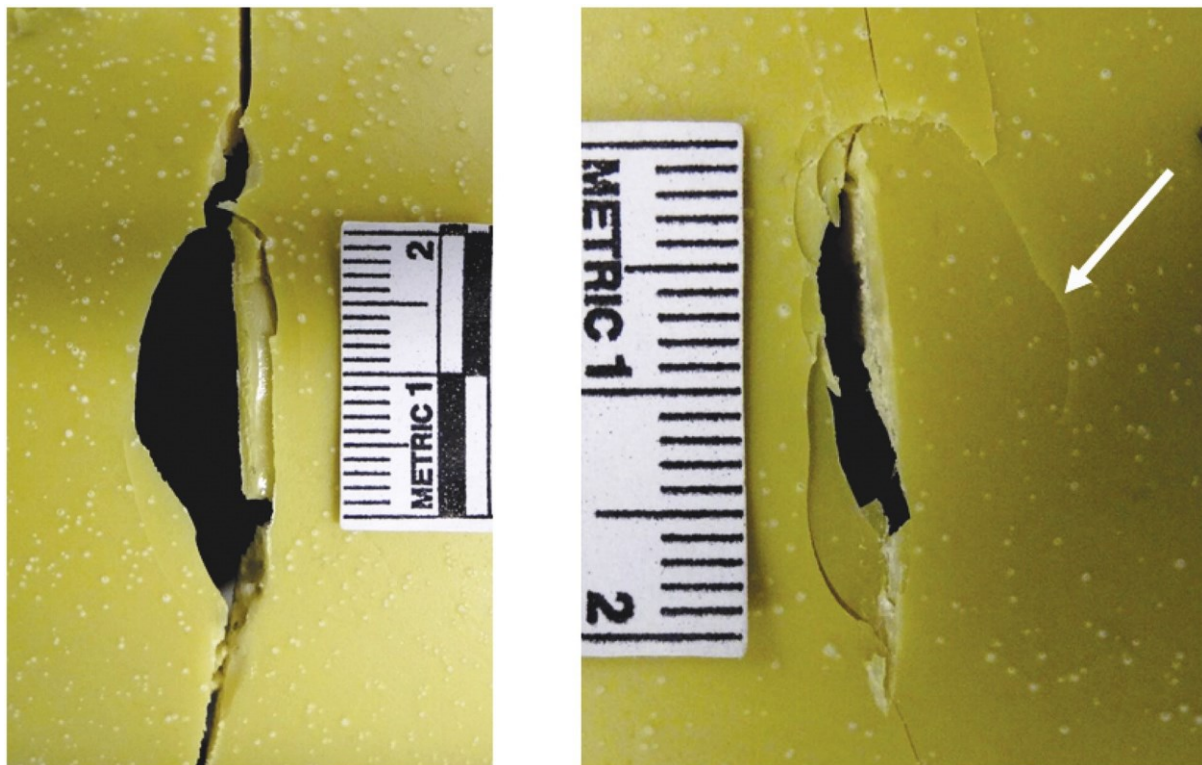


Fig. 5. Characteristic axe trauma, strike 8 (left) and strike 7 (right). Strike 7 features hairline concentric fracture.

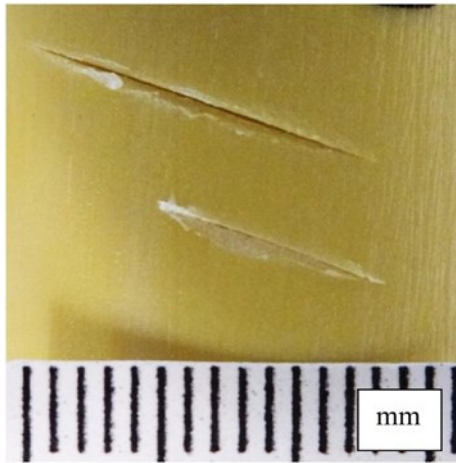


Fig. 6. Characteristic SF incision (strike 5).

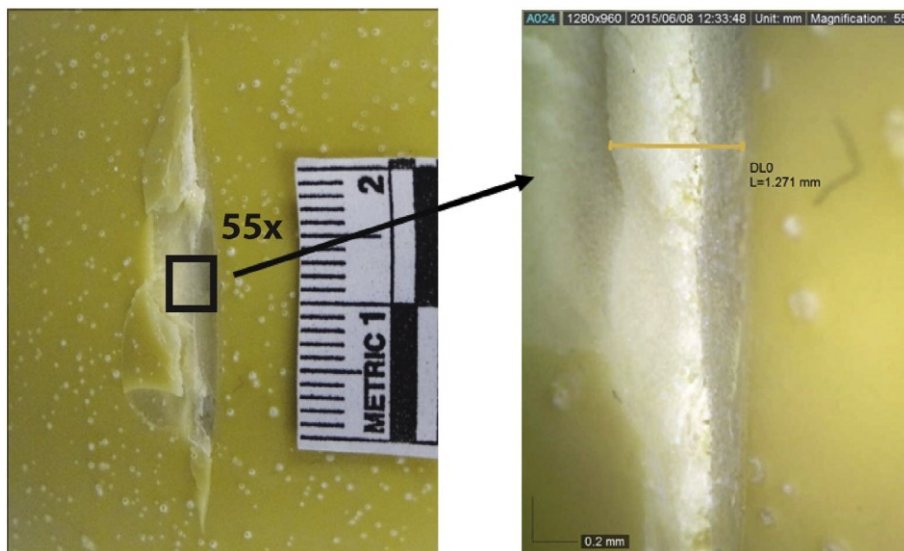


Fig. 7. Strike 9 – wide entry site with narrow kerf floor (oblique blow delivered from right).

4.4. Diagnosing weapon class

Diagnosing weapon class was particularly challenging due to the small sample size, which prevented any statistical analyses to differentiate weapon type, and due to the similarity of the BA blades in size. All the BA blades employed are short, light and have narrow cutting edges of roughly similar dimensions (see Table 1). Not surprisingly therefore the width of the cutmarks was not diagnostic of weapon class, which is consistent with previous findings (Bartelink et al., 2001; Maples, 1986).

Metrically, the length of the blades is a primary discriminator between the weapons used in this study. However, this distinction was not reflected in the cutmarks generated. For example, length of the sword and axe cutmarks were largely overlapping, despite the blade length of the sword being over eight times the length of the axe.

Morphologically, the sword marks are consistent with SF incisions created by a narrow blade used in a slashing motion (see Table 3). In terms of distinguishing weapon class, however, the sword marks generated in the current study are very similar to knife cutmarks in previous studies

(e.g. Lewis, 2008; Reichs, 1998; Shaw et al., 2011). For example, based on Lewis' (2008) criteria for distinguishing sword and knife marks, the sword marks in the current study were more similar to knife marks than sword marks, being shallow, narrow cuts with little damage to the sides on perpendicular strikes, although kerfs are generally straight. Furthermore, the shallow penetration of the sword marks, which in no instance penetrated into the internal table of the cranium or the medullary cavity of the long bone, can be contrasted with the SFT recorded in the human remains from the medieval battlefields of Wisby and Towton (Inglemark, 1939; Novak, 2000). Although shallow cutmarks were present in these remains, the medieval blades generally created more significant damage. For example, Novak noted that 70% of the SF injuries recorded in the remains from the battle of Towton were large and deeply penetrating, while only 30% were superficial cuts, slices and blade skips (Novak, 2000).

Morphologically the axe cutmarks are consistent with the criteria outlined in previous work on hacking weapon classes. One of the key differentiating features between chopping/hacking trauma and slashing/stabbing is that hacking creates much more significant wastage and is more likely to generate terminal fractures (Alunni-Perret et al., 2005; Reichs, 1998; Wenham, 1989) as seen in this experimentation.

In the Synbone crania, axe wounds could also be distinguished from sword/dirk wounds due to the curvature of the axe wounds in comparison to the linearity of the sword/dirk cuts (see Fig. 8). The axe strike to the long bone was more difficult to differentiate from a sword wound apart from the degree of breakage, as macroscopically, the kerf could not be differentiated from an 'incision-type' wound delivered with a slashing weapon, being not very deep, relatively narrow and v-shaped in cross section. Microscopically, it was found that the kerf was slightly wider than the kerfs in the perpendicular sword blow however, as it was only one specimen, further evidence would be needed prior to using this as criteria in distinguishing BA sword from axe blows. This is consistent with the results of Alunni-Perret et al. (2005) who found that they were able to distinguish between knife and hatchet wounds microscopically but macroscopically they were very similar.

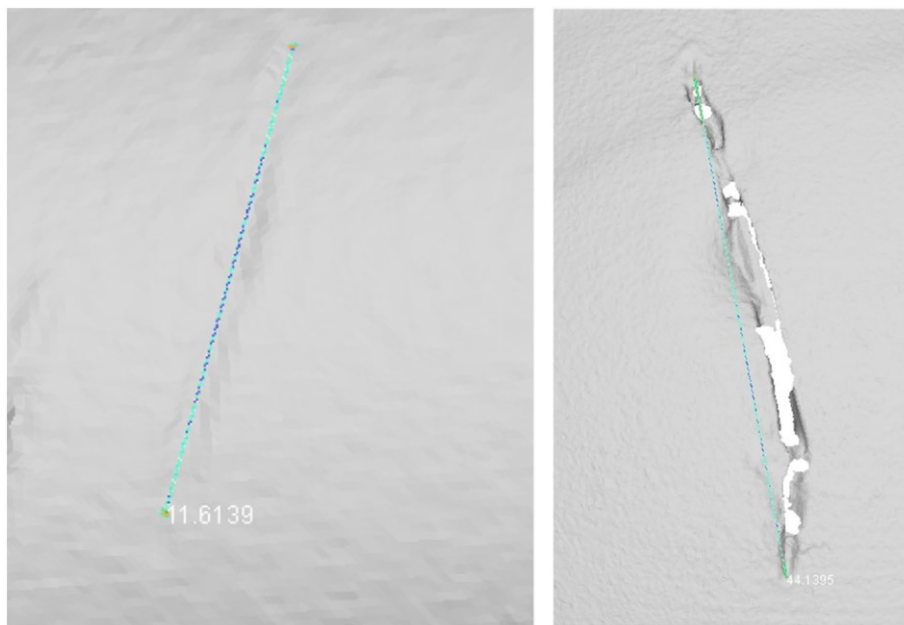


Fig. 8. 3D digital model of sword cut (strike 5) (left) and axe cut (strike 8) (right).

Recently, promising results have been obtained in several studies examining the potential of three-dimensional technologies in the analysis of cutmarks (e.g. Bello and Soligo, 2008; Boschini and Crezzini, 2012; Gaudio et al., 2014). In this study, 3D digital models of the cutmarks were created using a 3D surface scanner and AMIRA software. Unfortunately, due to the small dimensions, particularly in width, of the cutmarks (see Fig. 6) this method did not provide enough detail to improve upon information obtained from traditional microscopic and macroscopic examination.

Further research into the three-dimensional virtual reconstruction of the micro-morphology of cutmarks (e.g. Bello and Soligo, 2008) may provide improved analysis for the quantification of the generally narrow, shallow cutmarks generated with the BA sword and dirk.

Diagnostic criteria for separating dirk wounds from sword wounds were not attempted due to the limited data collected on wound morphologies generated with the BA dirk. While promising, the results of this research are limited by the small sample size and further research is recommended to test these findings on a larger sample.

4.5. Weapons

A second key aim of the current study was to provide experimental evidence for the effectiveness or functionality of BA weapons against skeletal tissues. The functionality of BA weapons is still a topic of considerable debate with some scholars suggesting that BA weapons would have been ineffective in combat, owing to the weapons being short and light as well as weaknesses in the weapon design (e.g. Burgess and Gerloff, 1981; O'Connor and Cowie, 1995) while other scholars have suggested that experimental and weapon use-wear studies do not support these assertions (e.g. Bridgford, 1997; Horn, 2013; Molloy, 2010). In this study, the severity of injuries generated on Synbone was assessed to determine the effectiveness of a BA sword, dirk and axe against human hard tissue.

In Inglemark's study of the skeletons from the battle of Wisby he grades the severity of battle-related injuries on a three-point scale: superficial cuts, which do not fully penetrate the compact layer of bone; cuts that penetrate to the medullary cavity, and cuts that completely sever bones (Inglemark, 1939). Using this scale both the sword and dirk injuries are judged to be superficial cuts while the axe damage is much more substantial with complete penetration of the internal table of the cranium and completely severing a long bone specimen. In terms of the functionality of the weapons tested all three weapons were able to penetrate the outer cortex of the Synbone specimens, leaving hard tissue damage.

This study is only a first step in determining the performance of BA weapons against human skeletal tissues and further research using both hard and soft tissues would further illuminate the functionality of these weapons. It should be remembered that fatal soft tissue injuries can be sustained without any skeletal damage, and the severity of hard tissue injuries may not necessarily be indicative of the clinical severity of the injury (Gurdjian et al., 1950; Gurdjian and Webster, 1958). This is particularly true in the cranium where it has been demonstrated that there is no direct correlation between the severity of injury and the presence or absence of fractures (Gurdjian et al., 1950).

Another important limitation of the current study relates to the experimental design. It is extremely difficult to simulate skeletal trauma sustained from an actual combat situation in a lab (Dolfini and Crellin, 2016, p. 81). In this case an effort was made to create an experimental design that reflected combat, however, key limitations of this set up are that the Synbone specimens were stationary and therefore do not have the same elastic response as the human body when struck. This is particularly important when considering how BA weapons were used. The trauma sustained from an attack with a BA sword would generally come from incision and laceration as these swords were too light to effectively use percussion as the primary force of the attack (Molloy, 2007, p. 95). The stationary nature of the targets made it difficult to effectively draw the sword across the target using the shoulder and upper body (Molloy, 2004, p.33) especially to an inexperienced sword user. This may have resulted in a slight increase in percussive force of the blow.

Nonetheless, as this was a preliminary study and the trauma inflicted with the BA sword used at a 90° angle did not show any characteristics typical of percussive force such as wastage and fracturing we feel the results of the current study still provide feasible evidence for the efficacy of BA weaponry against skeletal tissues. Furthermore, the BA flanged axe and Wilburton type sword

were able to damage skeletal tissue without sustaining any damage to the weapons, providing support for the argument that these weapons were functional and efficient in BA combat. This is in contrast to arguments that BA weapons were too small and flimsy for use in combat (e.g. Burgess and Gerloff, 1981; O'Connor and Cowie, 1995).

4.6. Synbone

This study proposed to test the applicability of Synbone as a human hard tissue analogue in SFT research. Previous studies have generally used animal tissue proxies for human tissue (e.g. Bartelink et al., 2001; Cerutti et al., 2014; Shaw et al., 2011), however, it was felt that some of the limitations associated with the use of animal tissues, such as increased overlying tissue thickness, might be particularly problematic with the use of bronze weapons. As experimentation with human tissues is limited by ethical considerations, Synbone was hoped to provide a useful experimental alternative to animal tissues that more closely replicated human bone structure. Although Synbone has been demonstrated to be an adequate human tissue analogue in several BFT and ballistics studies (e.g. Gläser et al., 2011; Thali et al., 2002), the results of this study suggested that Synbone may not be ideally suited to replicate human skeletal tissue in SFT research. Macroscopically, the Synbone performed well as a skeletal tissue analogue, replicating cutmark morphology seen in previous SFT research. In contrast, microscopically the Synbone did not replicate some of the pertinent features outlined in previous work. Similar conclusions were reached by Smith et al. (2015) in their experimental examination of Synbone as a proxy for human bone in ballistics trauma.

5. Conclusions

Skeletal SFT provides our most direct evidence for the use of bladed weaponry in the past however it has been underutilized as a source of evidence in discussions of violence and weapon use in the BA. Osgood et al. suggest, “although almost no dagger wounds have been found, or at least almost none recognized as such, this weapon was an important part of the warrior panoply at the start of the Bronze Age” (Osgood et al., 2000, p.140). The purpose of this study was to enhance our understanding of violence and weapon use in the BA by testing current methods for STF analysis on trauma generated with three replica BA weapons. The study also aimed to contribute to our understanding of violence in the BA by testing the effectiveness of BA weapons against skeletal tissues.

In this study, experimental combat with a BA sword (Wilburton type) and axe (flanged) demonstrated their potential to be effective weapons in combat and perceived weaknesses in BA weapon designs were not supported. The results of the study suggest that existing methods for cutmark analysis are generally applicable to injuries created with BA weapons when taking into account the size of the weapons. Criteria have been suggested for distinguishing axe and sword trauma generated with BA blades.

This study provides an important first step in the experimental investigation of BA skeletal trauma. Future research efforts will hopefully expand on the data generated from this project and include more weapon types, attackers and a larger skeletal tissue sample in order to gain a greater understanding of the potential variation of wound patterns. Additionally, the use of 3D technologies to document and examine the micro-morphology of cutmarks (e.g. Bello and Soligo, 2008) is a promising area of research to be further explored.

Footnotes

¹ http://www.legislation.gov.uk/ukpga/2004/30/pdfs/ukpga_20040030_en.pdf

² For more information about Synbone please visit their website: <https://www.synbone.ch/wEnglish/index.php>

³ See <http://www.loadstarsensors.com/impact-force-measurement.html?view=default> for more information.

⁴ <http://www.bronze-age-swords.com/intro.htm>

⁵ E.g. https://www.youtube.com/watch?v=_K5mlWcovJs; <https://www.youtube.com/watch?v=T4fUjmAnt-8>

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